April 1979

RESEARCH NOTE RM-366

FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Duration of Snow Accumulation Increases after Harvesting in Lodgepole Pine in Wyoming and Colorado

Howard L. Gary, Principal Hydrologist
Rocky Mountain Forest and Range Experiment Station[1]

North-south alternate stripcuts accumulated 15 to 60% more snow than similar widths of uncut forest. Part of the increase apparently resulted from redistribution of snow along the windward clearcut-forest interface. Data from a commercially clearcut area and 2H wide study plots indicated increased snow accumulation persists for decades, perhaps the life of the surrounding residual forest.

Keywords: Watershed management, land-use planning, clearcutting, snow hydrology, water yield management.

The 3.9 million acres (15,783 km^2) of lodgepole pine (*Pinus contorta* Dougl.) on commercial forest lands in Colorado and Wyoming occupy an important water producing zone and, thus, offer opportunities for complementing silviculture and water yield improvement practices. The recommended silviculture system for optimum redistribution of snow for water yield improvement in the lodgepole pine forests is clearcutting in small blocks or strips (Leaf 1975). The general prescription is blocks or strips less than 8 tree heights (8 H) in width, protected from wind and spaced at least 5 H apart. In some situations larger cutting units may be justified for disease control.

Studies of snow in lodgepole pine forests generally have shown greater quantities of snow in small openings and clearings and/or in thinned stands than beneath undisturbed forests (Niederhof and Dunford 1942, Wilm and Dunford 1948, Goodell 1952, Miner and Trappe 1957, Berndt 1965, and Dietrich 1973). These authors generally attribute accumulation differences to interception losses. A comprehensive study of the Fool Creek watershed in Colorado indicated no increase in snow as a result of alternate stripcutting but showed there was significant redistribution of snow from the undisturbed forest to the cut areas (Hoover and Leaf 1967). At present it is generally concluded forest openings and forest margins must be considered as a whole in evaluating effects of harvesting on snowpack accumulation (Anderson 1969, Gary 1974).

Dynamic simulation models of the long-term effects of forest and watershed management indicate water yield increases after small patch cuts may persist for at least 50 and perhaps 60 or more years (Alexander and Leaf 1975). However, the long-term effect and time trend of clearcutting in small blocks or strips on snow

[1] *Central headquarters maintained at Fort Collins, in cooperation with Colorado State University.*

redistribution has not been generally validated. This study reports some long-term effects of harvesting on snow redistribution and the probable duration of the effects.

Study Area and Methods

Lodgepole forests in southern Wyoming are generally found at elevations between 2,450 and 3,500 m (Tackle 1959). Annual precipitation is generally greater than 450 mm, with one-half to three-fourths as snow which persists until about May. Similar elevations and precipitation patterns characterize lodgepole pine areas in Colorado. Lodgepole pine elevations in northern Wyoming are slightly lower.

The general study area was in an extensive forest of lodgepole pine in southern Wyoming. The area is on a gently rolling plateau about 2,740 m above sea level, well exposed to prevailing southwesterly winds. The area is usually snow-covered from late November to early May. Little melt occurs under the forest cover until April. Snowfall amounts are usually low but account for about one-half of the annual precipitation of 450 to 500 mm.

Snow Accumulation in Alternate Strips

Measurements were taken in an extensive and mature lodgepole pine stand which had been harvested for wood products by strip-cutting in 1955-1959. The strips were between 125 and 150 m wide and about 1.6 km long. Strips were oriented north-south, mainly on gentle southerly exposures. Today the cut strips are generally well stocked with lodgepole pine regeneration. Some have been thinned. Heights of new dominants and co-dominants in the strips range from 3 to 6 m. The leave strips of the remaining mature lodgepole pine stand averaged about 830 trees larger than 12.7 cm dbh per ha. Diameter averaged about 20.5 cm and basal area about 29.4 m^2/ha. The average height of the leave forest was about 15 m.

An east-west oriented snow measurement transect was established across four forested strips and four cut strips on a gently southfacing slope about 400 m from the ridgetop (fig. 1). A second east-west transect also was established across two forested strips and three cut strips on similar terrain on the adjacent

Figure 1.—Closeup of regeneration in one clearcut strip and adjacent forest in 1977.

north-facing slope, 100 to 200 m below the ridgetop. Sample points along transects were spaced about 10 m (0.5 chain) apart. Where necessary, distances were adjusted so sample points fell at each forest-clearing interface. The transect on the south-facing slope had 99 sample points and was about 1,000 m long. The transect on the north-facing slope had 68 sample points and was about 674 m long. Snow water equivalents were measured near the time of maximum snowpack (about mid-March), over a 3-year period from 1975 to 1977. All snow samples were obtained with a standard federal snow tube and weighed on a dial-type scale.

Simulated Duration of Effects of Harvesting on Snow

This part of the study simulated the duration of the effect of harvesting on snowpack accumulation. An even-aged stand (about 80 years old) located on level terrain was selected for study. The stand had been thinned in the late '30's by the Civilian Conservation Corps and had about 1,852 trees per ha. Tree diameters ranged from about 7.6 to 17.8 cm with an average of 12.7 cm. Basal area was about 23.8m^2 per ha. Average height of all trees was about 10.3 m.

Data were collected during the winters of 1975 and 1976. In October of 1974 a 2-H-wide clearing about 21 by 21 m was established. All trees and slash were removed from the cleared area. In an area about 25 m north of the first clearing all trees were cut down in a similar sized 2-H-wide area, leaving 1.22-m-tall stumps. A predetermined butt-end section, equivalent to one-half

of the original height (1/2 H) was removed from each of 85 trees. Each tree was then raised and bolted to its own stump (fig. 2).

In late October 1975 a third 2-H-wide plot was established 25 m north of the 1/2 H plot. In this plot one-fourth of the original height was removed from the butt-end of each tree (77 trees). The trees were then raised and bolted to their stumps to establish a new stand three-fourths as tall (3/4 H) as the surrounding forest. The tree sections not used in the 1/2 and 3/4 H plots were removed from the area. The needles on all the bolted up trees remained on the trees and were green and flexible until taken down early the next summer.

Eight east-west transect lines (equally spaced) were established across all plots and extended into the undisturbed forest on either side of the 2-H-wide clearing, the 1/2 H and the 3/4 H plots. Snow sampling points along the transects within treated areas were spaced 1.5 m apart. Sample point locations along the transect sections extending into the upwind (west) forest were 1.5, 3.0, 6.0, 12.0, and 18.0 m for each plot. Sample point spacing on the downwind (east) sides of the plots were the same, except two additional sample points were established at 24 and 30.5 on each transect.

Time-Trend of Effects of Harvesting on Snow

Snow data collected periodically over the last 30 years for a continuing study on the Fraser Experimental Forest in north central Colorado was also analyzed to determine time-trend of harvesting effects on snow-accumulation. Wilm and Dunford (1948) reported initial results of the commercial clearcut harvesting. They described the study area as having 740 to 988 trees/ha larger than 8.9 cm dbh. Maximum diameter was about 56 cm. Heights ranged from 10.7 to 25.9 m with a few valley-bottom trees over 30 m high. In 1940 four harvesting levels and one control were applied to 20 plots 2 ha in size within 4 randomized blocks. Treatments of most interest for the present study included the extremes in plots with commercial clear-cutting of all trees larger than 24 cm in diameter and the plots with no logging.

Figure 2.—Canopy of the undisturbed forest and for trees reconstructed to one-half their original height (1/2 H). Method of bolting to stumps inset.

Results and Discussion

Snow Accumulation in Alternate Strips

Snow water equivalents for sample points along the two transects provided strong evidence that greater average quantities of snow were in the clearcut strips, even during the extremely dry winter of 1977 (fig. 3). Individual point-to-point snow samples were widely variable both within and between the alternate cut and leave strips. Some of the variation in the cut strips appeared to be the result of old slash holding snow against the prevailing southwest winds. In the forest small open spaces and the ragged character of the over mature canopy allowed the snowpack to accumulate in a variable pattern. The widely fluctuating point samples of snow-water equivalents along the transect in the alternate forest strips differed from the generally smooth pattern of point to point samples observed under an 80-year-old lodgepole pine stand in the same vicinity (Gary 1975).

Low snow accumulation near the windward clearcut-forest interfaces (fig. 3) was a common characteristic on both north and south aspects in the alternate strip area. The same pattern is also observed in clearings 1-H wide (Gary 1974). The apparent snow deficit zone along the windward edge of the forest leave strips was strongly influenced by wind. However, no definite excessive deposits of snow attributable entirely to wind transport were observed in the forest interior. For the local area in general dry soils were found at most clearing-forest interfaces during mid-winter. The dry soils apparently indicate early melting is not a major cause for the commonly observed snow deficit zones.

The magnitude and combination of wind processes transporting snow from the clearing-forest interface vary from storm to storm, but the effects are cumulative over winter and help produce the snow deficit zone. One hypothesis accounting for some of the snow deficit zone is that strong back eddies of airflow and saltation processes at the snow surface during and after each snowfall transport some snow away from the lee clearing-forest interface into the clearings. Cumulative snow buildup then occurs in the clearings in low windspeed zones (Gary 1975). Zones of low snow accumulation were not generally present along the windward forest-clearcut interfaces because wind velocities are reduced (fig. 3).

Differences in snow accumulation in the clearcut strips and leave forest strips are summarized in table 1. In all years and on both slope aspects water equivalents were larger in the clearcut strips. The greatest differences were on the south aspect (41 to 60% more snow) and were apparently the result of greater exposure to prevailing southwest winds. On the north aspect the clearcut strips had 15 to 30% more snow than did the adjacent undisturbed forest strips.

Simulated Duration of Effects of Timber Harvesting

The physical manipulation of tree heights provided some insight to the expected duration of the effects of patch cutting on snow

Table 1.—Average snow water equivalents in alternate clearcut and undisturbed forest strips on north and south aspects

Aspect and site	Number of samples	Water equivalent 1975	1976	1977
North aspect				
Clearcut strips (C)	40	229	229	91
Undisturbed forest (F)	28	183	175	79
Percent increase (C over F)		25	30	15
South aspect				
Clearcut strips (C)	55	218	198	102
Undisturbed forest (F)	44	155	124	66
Percent increase (C over F)		41	60	55

accumulation. Snow water equivalents measured in the one small cut patch and on two nearby plots with adjusted tree heights are illustrated in figure 4. During both years the small clearing had about 30% more snow water equivalent than the upwind forest, but the characteristic snow deficit zone was also present along the leeward forest side of the clearing. The greater snow accumulation in the clearing itself appeared in large part to be caused by redistribution as a result of back eddies in the airstream above and at the snow surface both during the following storms. Reduced interception loss appeared to be another factor. Volume computations based on increased snow catch in the small clearcut and decreased snow catch along the leeward forest

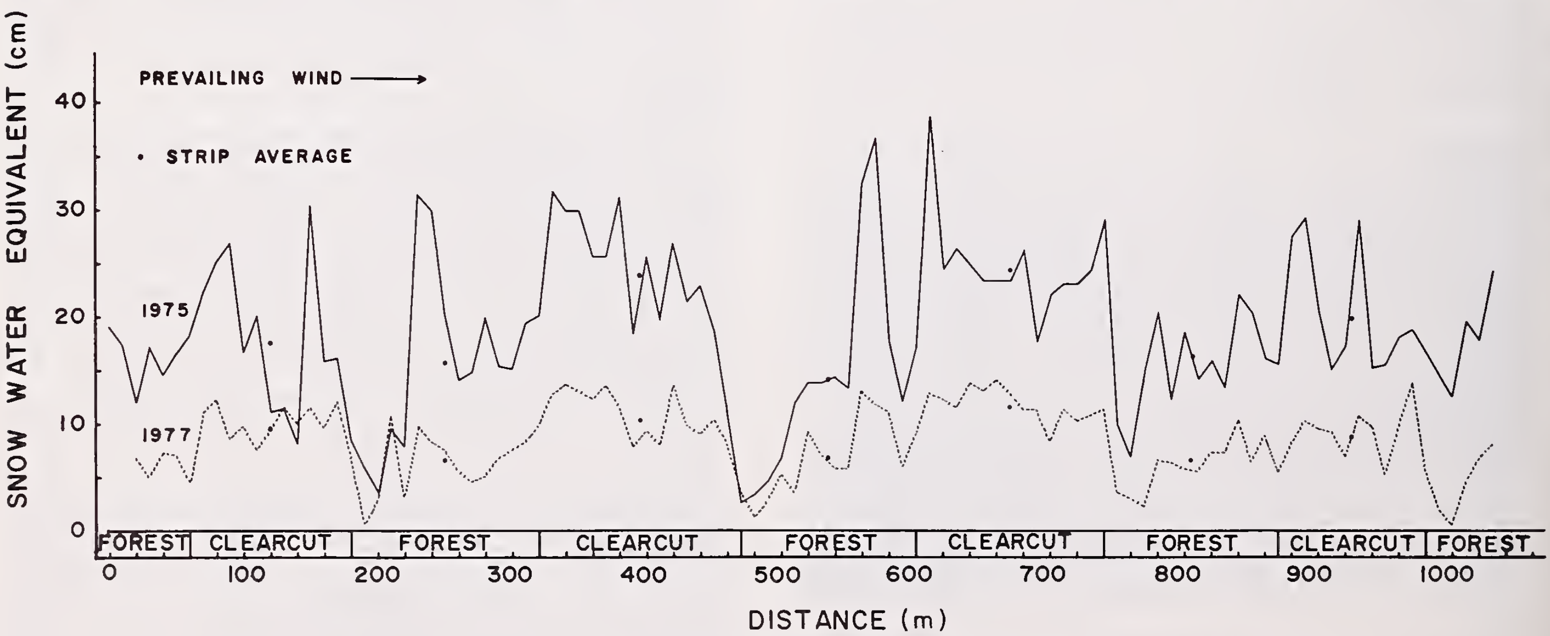


Figure 3.—Snow water equivalents across several cut and leave strips on a south aspect for two contrasting years.

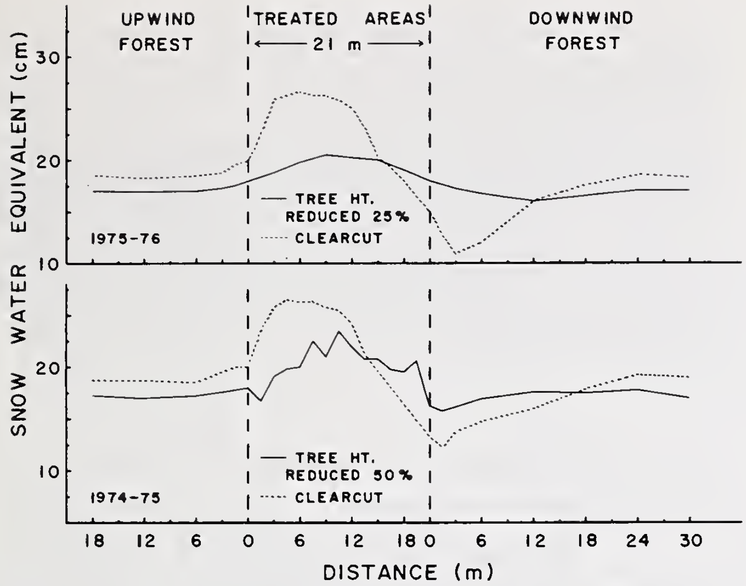


Figure 4.—Average maximum snow water equivalents in a 2-H-wide clearing during two winters and in 2-H-wide plots with tree heights reduced 1/2 H and 1/4 H.

border indicated a general equivalence between the greater and lesser snow accumulation zones (Gary 1974). The total measured increase in snow water equivalents attributed to the small clearcut plot for each of two winter seasons was less than 10 mm.

In the 1/2-H plot the lower branches of the crown of most trees were just above ground level. Snow sliding off of the crowns following storms accumulated mainly between trees, producing the uneven snow water equivalents in figure 4. Volume computations based on comparison with adjacent upwind and downwind forest indicated a 14% increase in snow catch (25 mm of water equivalent) inside the 1/2-H plot. Snow catch inside the 3/4-H plot averaged 13% more snow (23 mm more snow water equivalent) than was measured in the undisturbed forest.

The greater quantities of snow observed inside the adjusted-tree-height plots do not appear to be the result of redistribution processes, since the leeward snow deficit zones were not evident. The greater snow was apparently due to cumulative differential evaporation and/or sublimation losses between snow held by the undisturbed forest canopy and the protected lower level canopies over the 1/2- and 3/4-H plots.

The increased snow water equivalents in the small 2-H-wide clearcut plot and in the 1/2- and 3/4-H plots generally illustrated that small patches cut in lodgepole pine increase snow accumulation. The small 2-H-wide adjusted tree height plots also indicated increased snow accumulation will persist for several decades through the development of a new stand. After developing an age-height curve for lodgepole pine in the local area and by extrapolating from observed data in fig. 4, it was possible to illustrate the expected duration of snow redistribution in a small patch cut (fig. 5). For purposes of illustration, a patch cut about 2 H wide was made in a 90-year-old lodgepole pine stand. It was further assumed forest regeneration occurred within 1 year (complete regeneration would probably take up to 10 years or longer). The age-height curve for the new stand is the same as shown for the residual forest, except for displacement in time. It was also assumed the growth and management of the new stand will be similar to that in the residual forest.

Snow water equivalents (observed in fig. 4) the year after making the small patch cut show a 30% increase as the result of snow redistribution processes (fig. 5). When the new stand

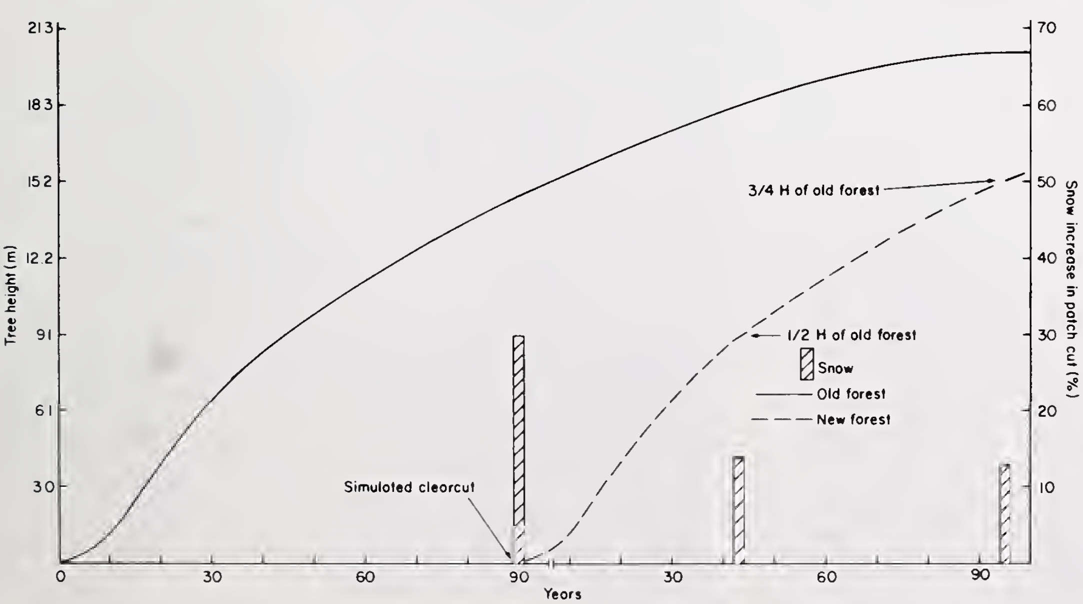


Figure 5.—Age-height curve for old-growth lodgepole pine, simulated forest regeneration after patch cutting a 2-H-wide area and the probable long-term duration of increased snow accumulation.

reaches 1/2 H of the residual forest, some 40 years later, the snow catch is only 14% higher than in the residual forest. About 90 years after establishing the new stand (when the new stand is about 3/4 of the residual forest) the snow catch would be about 13% above that expected in the residual forest.

The data contained in figure 5 are subjective, but illustrate the probable long-term duration of patch cuts made to increase snow accumulation. Based on past research and other small clearcuts in the area, the simulated curves were generally applicable for small patches up to about 5 H wide.

Time-Trend of Effects of Timber Harvesting

Snow measurements taken periodically over a period of 38 years at 100 sample points in plots commercially clearcut and plots left uncut on the Fraser Experimental Forest are summarized in figure 6. In the preharvest period 1938-39 snow water equivalents averaged 11% greater over the plots later selected for commercial clearcutting. However, based on five measurement periods spaced over the last 21-year period (1956-1976), plots commercially clearcut in 1940 averaged about 37% greater snow water equivalents than the plots not harvested. The difference of 58 mm was significant at the 0.01 level. Analysis of variance for all data collected since harvesting in 1940 also indicated no significant treatment-year interaction. Total

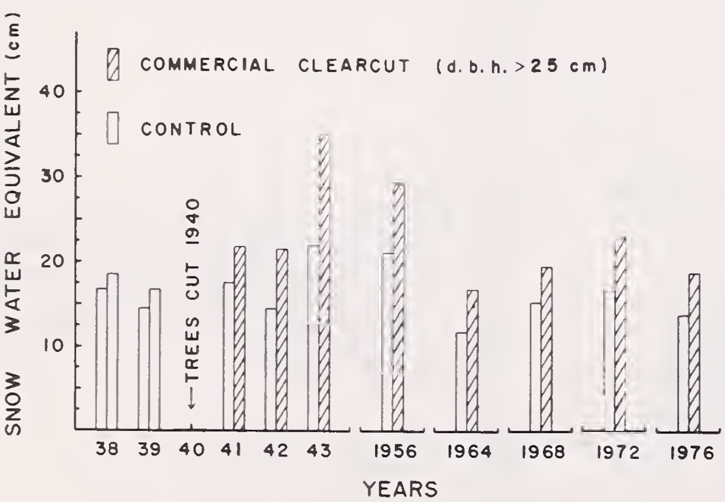


Figure 6.—Average snow accumulation over time for commercially clearcut and uncut lodgepole pine on the Fraser Experimental Forest.

annual growth increments in the first 20-year period after treatments were almost as great on the clearcut as on the uncut areas (Alexander 1966). However, differences in stand structure between the clearcut and uncut areas are today visually apparent, and the trend of increased snow accumulation as a result of the commercial clearcutting will apparently persist for many more years.

Summary and Conclusions

Data collected for three winters in alternate clearcut strips harvested about 25 years ago and in the leave forest strips showed 15 to 60% more snow in the harvested strips. Part of the increase in clearcut strips apparently resulted from redistribution of snow from lee forest strips. It is not known what effect the snow deficit zone in the lee forest had on subsequent tree growth.

Data from the 2-H-wide clearcut plot, the 1/2- and 3/4-H plots showed the pattern of increased snow accumulation will apparently be maintained during regeneration for several decades after harvesting, probably until the surrounding residual forest is harvested.

Observations from the Fraser Experimental Forest generally indicated new forest growth has little diminishing effect on increased snow accumulation for several decades following. However, due to new tree growth and increasing biomass in the commercially clearcut area, the greater quantities of snow probably do not imply sustained increases in streamflow of the same magnitude.

In the lodgepole pine type in Colorado and Wyoming harvesting timber in small patches and in narrow strips less than about 8 H wide caused accumulation of at least 30% more snow than surrounding forest. However, much of the increase was at the expense of snow accumulation along the lee forest borders. The increased snow accumulation pattern will apparently persist for several decades after regeneration of a new stand. Greater water yields can be expected from clearcut areas for many many years, apparently because of reduced transpiration losses, a greater unit-area concentration of snowmelt water, and greater year-to-year carryover of soil moisture.

Literature Cited

Alexander, Robert R. 1966. Harvest cutting old-growth lodgepole pine in the central Rocky Mountains. J. For. 64:112-116.

Anderson, Henry W. 1969. Snowpack management. *In* Snow. p. 27-40. Oreg. State Univ., Water Resour. Inst., Seminar WR 011.69. [Corvallis, 1969.]

Berndt, H. W. 1965. Snow accumulation and disappearance in lodgepole pine clearcut blocks in Wyoming. J. For. 63:88-91.

Dietrick, Thomas S. 1973. Management of Colorado mountain lands for increasing water yields, Vol. 2-Hydrologic effects of patch cutting of lodgepole pine. Final Rep. No. CSU-14-06-D-6598-2 to U.S. Bur. Reclam., Div. Gen. Res., Denver, Colo., 95 p.

Gary, Howard L. 1974. Snow accumulation and snowmelt as influenced by a small clearing in a lodgepole pine forest. Water Resour. Res. 10:328-353.

Gary, Howard L. 1975. Airflow patterns and snow accumulation in a forest clearing. West. Snow Conf. Proc. 43:106-113. [Coronado, Calif., April 1975].

Goodell, B. C. 1952. Watershed management aspects of thinned young lodgepole pine stands. J. For. 50:374-378.

Hoover, Marvin D., and Charles F. Leaf. 1967. Process and significance of interception in Colorado subalpine forest. p. 213-224. *In* W. E. Sooper and H. W. Lull (ed.), Forest Hydrology, 813 p. Pergamon Press, N. Y. [Int. Symp. For. Hydrol., Univ. Park, Pa., Aug.-Sept. 1965]

Leaf, Charles F. 1975. Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge. USDA For. Serv. Res. Pap. RM-137, 31 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Leaf, Charles F., and Robert R. Alexander. 1975. Simulating timber yields and hydrologic impacts resulting from timber harvest on subalpine watersheds. USDA For. Serv. Res. Pap. RM-113, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

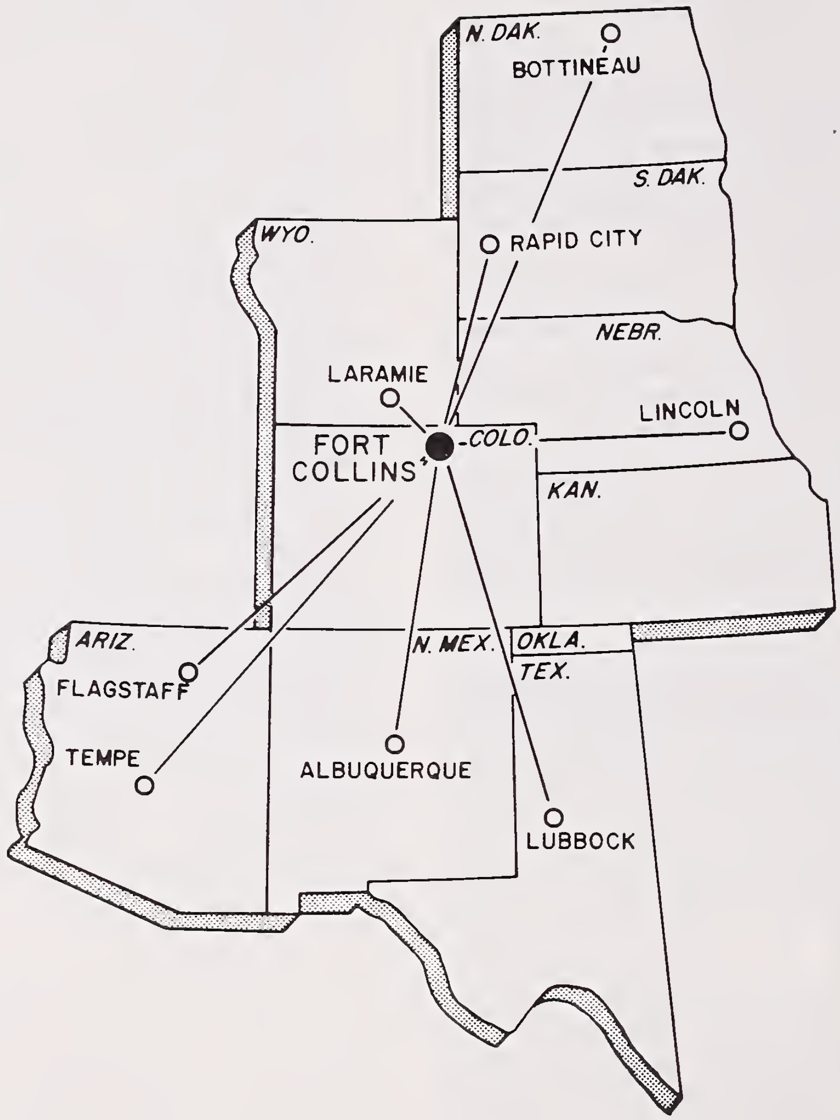
Miner, N. H., and J. M. Trappe. 1957. Snow interception, accumulation, and melt in lodgepole pine forests in the Blue Mountains of eastern Oregon. U.S. Dep. Agric., For. Serv., Pac. Northwest For. and Range Exp. Stn., Res. Note 153, 4 p.

Niederhof, C. H., and E. G. Dunford. 1942. The effects of openings in a young lodgepole pine forest on the storage and melting of snow. J. For. 40:802-804.

Tackle, David. 1959. Silvics of lodgepole pine. U.S. Dep. Agric., For. Serv., Intermt. For. and Range Exp. Stn., Misc. Publ. 19, 24 p.

Wilm, H. G., and E. G. Dunford. 1948. Effect of timber cutting on water available for streamflow from a lodgepole-pine forest. USDA Tech. Bull. 968, 43 p.

Agriculture — CSU, Fort Collins


N. DAK.
BOTTINEAU
S. DAK.
WYO.
RAPID CITY
NEBR.
LARAMIE
LINCOLN
FORT
COLLINS
COLO.
KAN.
ARIZ.
N. MEX.
OKLA.
TEX.
FLAGSTAFF
TEMPE
ALBUQUERQUE
LUBBOCK